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A Multiplexer System for Measurement of Gaseous Emissions

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Abstract. A multiplexer was designed for measurement of gaseous emissions from ground level area sources (GLAS) in order to sample multiple receptors with a single sensor. This multiplexer may be used in both local and remote measurements systems to increase the sampling rate of gaseous emissions. The multiplexer, when used in the local mode, is divided into three distinct control sections: lift control, zero air input, and sample control. When used in remote mode, only the sample control is used. The multiplexer uses LabVIEW software to control Fieldpoint distributed I/O modules (National Instruments). The increased data collection capacity with the multiplexer allows for nearly twice as many samples to be taken in the same amount of time while using the same protocol for sampling.

Keywords. Multiplexer, gaseous emissions, hydrogen sulfide, ammonia, flux chamber, air pollution, air quality

Introduction

The Center for Agricultural Air Quality Engineering and Science (CAAQES) uses several methods to measure ammonia and hydrogen sulfide from ground level area sources (GLAS). These measurements are primarily taken from Confined Animal Feeding Operations (CAFO). Generally, CAAQES has used a method detailed by Kienbusch (1986) using emission isolation flux chambers to measure ammonia and hydrogen sulfide emissions. With the recent acquisition of two 17C (Thermo Inc. Franklin, MA) ammonia analyzers, one 45C hydrogen sulfide analyzer, and one 450C hydrogen sulfide analyzer, a study was performed to increase the performance of field sampling. With the increasing cost of field sampling, every process step was examined to decrease the time of sampling. This study focused on data management, time management, and protocol development. The goal of this paper is to present the design of the multiplexer system used by CAAQES to estimate gaseous emissions.

Sampling Methodology

The flux chamber method is based upon the two-film model (Jiang & Kaye, 1996). The two film model relates the emission flux of a gas to the concentration of the gas in the liquid using Henry's Law and diffusion. Several factors affect Henry's law and diffusivity, including concentration gradient, temperature, and pressure. These factors are often not addressed by those using the flux chambers. Humidity can largely affect measured emissions since water can combine with volatilized ammonia. The "sponge effect" of water may skew the rate measurements downward. Since the atmosphere is generally isolated in an isolation flux chamber, changes in pressure and temperature affect the emission rate. These biases must be corrected so that the proper emission rate may be found.

The method of flux chamber sampling is described in detail by Kienbusch (1986) in *Measurement of Gaseous Emission Rates from Land Surfaces Using Isolation Flux Chamber*. The CAAQES protocol follows this method with the following procedure. Upon arriving at the CAFO, the site is divided into various manure handling, storage and treatment, and animal confinement units. This allows for a method to identify areas which are emitting large amounts of the measured gases. For example, a dairy in Central Texas may be divided into free stalls, open lots, solids separation, lagoons, and composting operation. Each of these units is further divided into random samples. The number of samples depends on the surface area and consistency of the area. Statistical analysis is used to determine the number of samples required for each unit. From experience, more samples are taken from the free stalls per unit area than from the lagoon since the surface and solution are more consistent for the lagoon than the free stall area.

The sampling process begins when the chamber is placed on the GLAS. A flow rate of 7 L/min (21°C, 1atm) of Zero Air from a gas cylinder or Zero Air Generator (AADCO 737-12A, Village of Cleves, OH) is pumped into the chamber as a sweep air. Zero air is air which has been purified to remove pollutant gasses. Two liters per minute (21°C, 1 atm) are drawn from the chamber and split into one hydrogen sulfide analyzer and one ammonia analyzer. The chamber is vented to the atmosphere so that the remaining 5 L/min exit the chamber. The chamber is flushed for thirty minutes followed by thirty minutes of sampling.

Originally, only one flux chamber was used by CAAQES to sample emissions from CAFOS. The sampling process took approximately 1 hour to sample plus 5 to 15 minutes to move the flux chamber from one location to another. The flux chamber required 15 minutes to move when sampling the lagoon and approximately 5 minutes to move on dry surfaces. The total time required to obtain a sample was approximately 1 hour 15 minutes. LabVIEW 5.1 was the programming language of choice for the original setup. Three programs were required to obtain data and control the gas flow to and from the chamber. The first program controlled the flow rates using a mass flow controller (MFC series, Aalborg Instruments, Orangeburg, NY) via a DAQCard (AI-16-XE-50, National Instruments, Austin, TX) coupled with two digital to analog converters (Maxim 544, Dallas Semiconductor, Sunnyvale, CA). The second program logged data from the analog outputs of the analyzers. These outputs were logged every 5 seconds. Temperature data from the ambient air, flux chamber, and source were also recorded every 5 seconds. The 5 second data proved to be cumbersome to analyze and the 1 minute data was determined to be sufficient for estimating gaseous emissions. The third program provided concentration data via the RS-232 serial port from the analyzer. The digital and analog data each were logged into a file.

Calibration of the analyzers involved attaching a gas cylinder of known concentration to the system. The calibrated gas was mixed with zero air to reduce the concentration of the gas as needed. A static mixer (1/2-80-PFA-12-2, Koflo Corporation, Cary, IL) was used to mix the gas thoroughly. The calibration was complete when the concentration changed less than 1% in 5 to 7 minutes.

As data collection progressed, a few shortcomings with the original setup became apparent. First, the single chamber only allowed the sensor to be used less than half of the time. This limited the total number of samples to approximately 35 for a 4 day sampling period. Data management was also a problem. Data was lost and was difficult to manage because of the multiple program structure. The non-integrated program structure was also difficult for the user to navigate.

As a result, a new integrated system was proposed for which analyzer downtime was almost zero. The new system multiplexed three chambers for each set of ammonia and hydrogen sulfide analyzers. This allowed the analyzers to be used continuously throughout the sampling trip. The system allowed collection of over 80 samples during a four day sampling period from a single analyzer. Because of the increased amount of data received from the analyzers, a good data management system was essential.

System Design

The multiplexer system allowed multiple receptors to be sampled using a single analyzer. Three chambers could be placed on an emitting source and samples taken sequentially. Figure 1 shows a diagram of the multiplexed chamber setup with one chamber shown. Two other chambers are similarly connected to the multiplexer with the connections shown.

The multiplexer system controls three major processes: zero air flow, sample flow, and chamber lift. The chamber must be lowered at the beginning of each test. After the chamber is lowered, the zero air flow begins and remains until the end of the sample. The chamber is flushed for 30 minutes followed by a 30 minute sample. The chamber is flushed to remove effects due to the response time of the chamber. The chamber is lifted at the end of the sample so that it may be relocated for the next sample.

An aluminum enclosure was built to house the components of the multiplexer as well as the analyzers. The enclosure was built so that it could be pulled with an all terrain vehicle. This allowed the two analyzer units to be positioned up to 50 m apart from each other. The enclosure was sized for a standard rack system and included an area for attachment of multiplexing valves. In the front of the enclosure, user controls, power connections, and flow connections were positioned for easy access. Two sides of the enclosure were designed to be fully removable for access to the various connections.

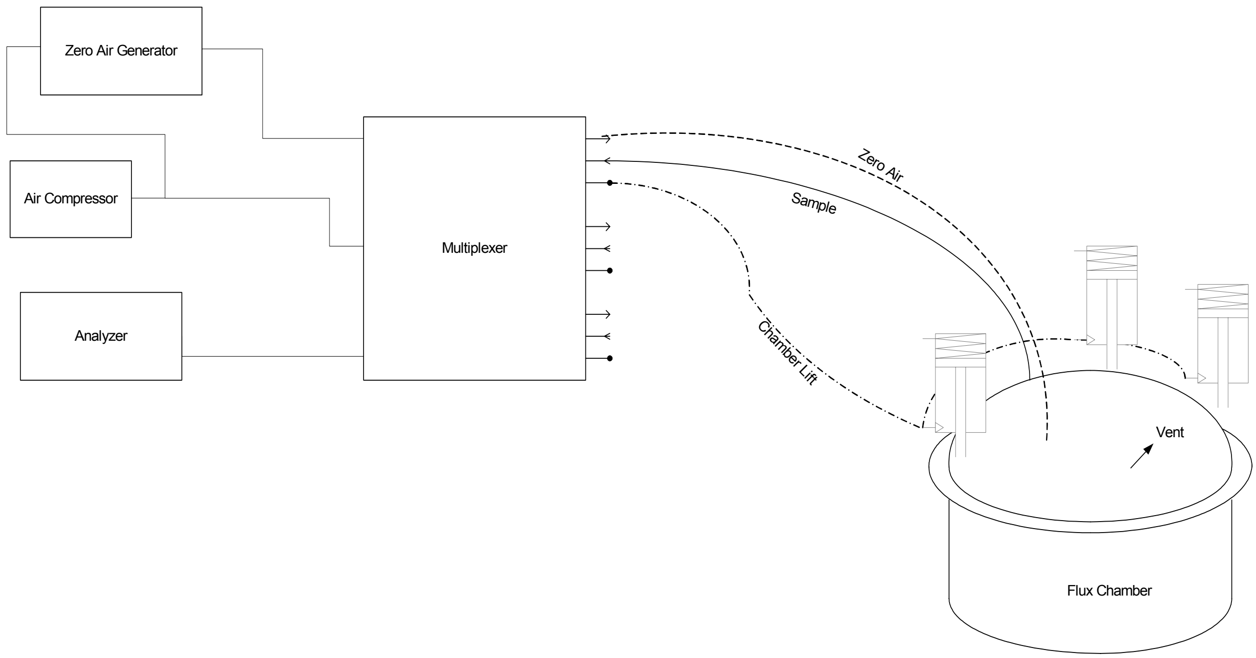


Figure 1. Multiplexed chamber setup.

The multiplexer control includes a series of solenoid valves that open and close to calibrate, run and flush the system. These valves are controlled via a computer through Fieldpoint modules (National Instruments, Austin, TX). LabVIEW 7 software is used as the control interface for the Fieldpoint modules. Mass flow controllers are used to adjust the zero air flow rate entering the chamber. Flow valves are used with mass flow meters to adjust the flow of air to be analyzed.

A schematic of the control system is presented in Figure 2. Chambers are controlled by a pneumatic lift mechanism to lower the individual chamber at the beginning of the test and raise the chamber at the end of the test. All of the chambers are initially in the upward position. An air compressor and air cylinders provide the force to lift the chambers. When the chamber is ready for sampling, it is lowered by releasing the pressure in the lines. Positioning the chamber is performed using 6 solenoid valves (S18-S23, Fig. 2; Gold Ring Series 20, Parker Hannifin Corp., Madison, MS).

Only two of the three chambers are used at any given time. Two mass flow controllers (MFC1& MFC2, Fig. 2; MFC series, Aalborg Instruments, Orangeburg, NY) are used to control the Zero air flow rate into the chambers. Manifolds and 6 solenoid valves(S1-S6, Fig, 2) are used to distribute the Zero air to the respective flux chambers.

Air from the chambers is drawn through Teflon PFA tubing into the enclosure where it is metered using a flow control valve (FV1-FV3, Fig. 2; #06393-80, Cole-Parmer, Chicago, IL). Six solenoid valves (S9-S14, Fig. 2) control the direction of flow. The valves are off when the chamber is inactive. Two flow directions may be chosen if the chamber is active depending whether the chamber is in flush mode or is in sample mode. A standard duty vacuum pump maintains the flow during flushing (first 30 minutes). A Teflon vacuum pump draws the flow to the analyzer during the sampling period. A mass flow meter (MFM1 & MFM2, Fig. 2) indicates the flow rate from the chamber. This allows for troubleshooting.

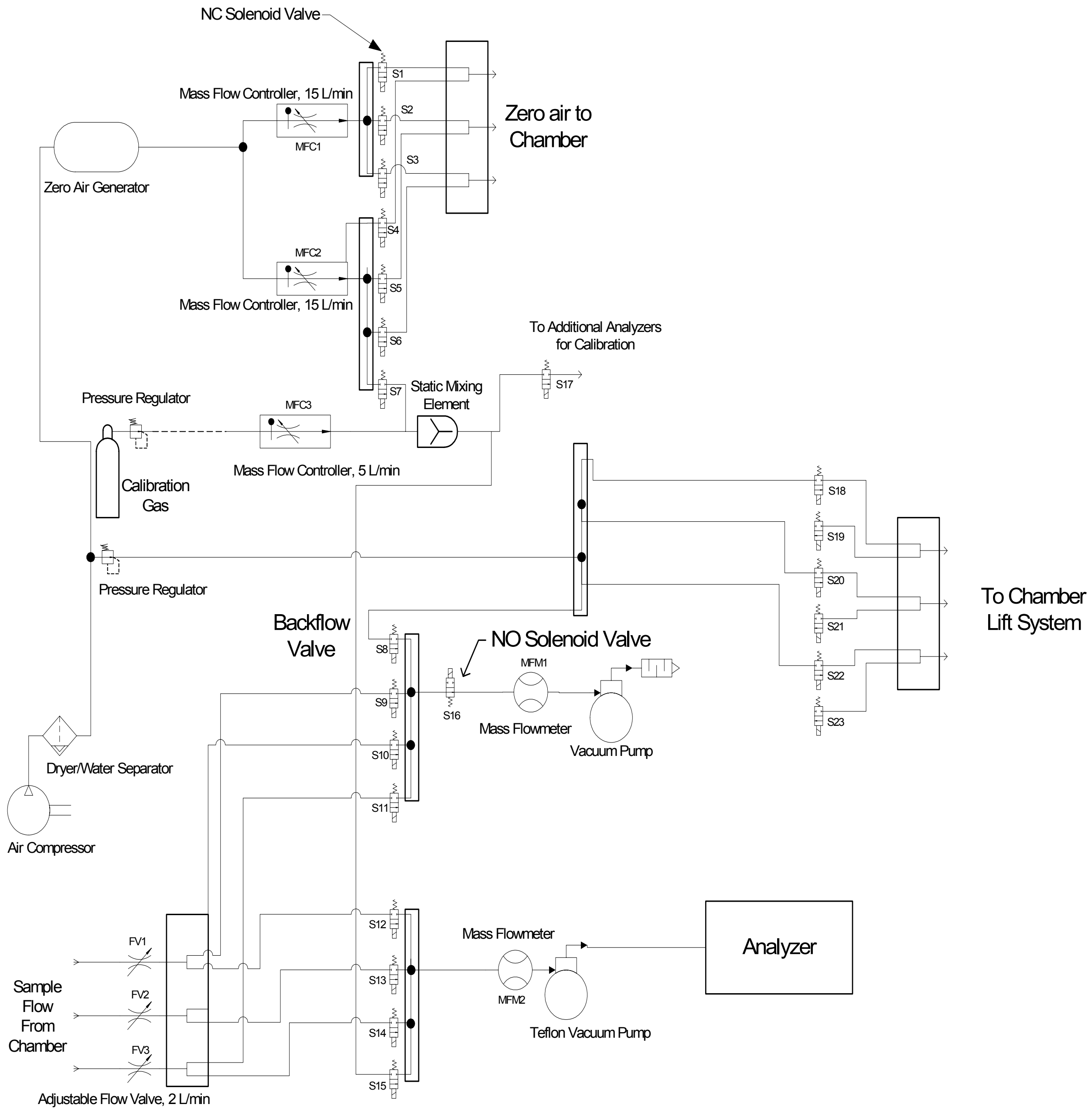
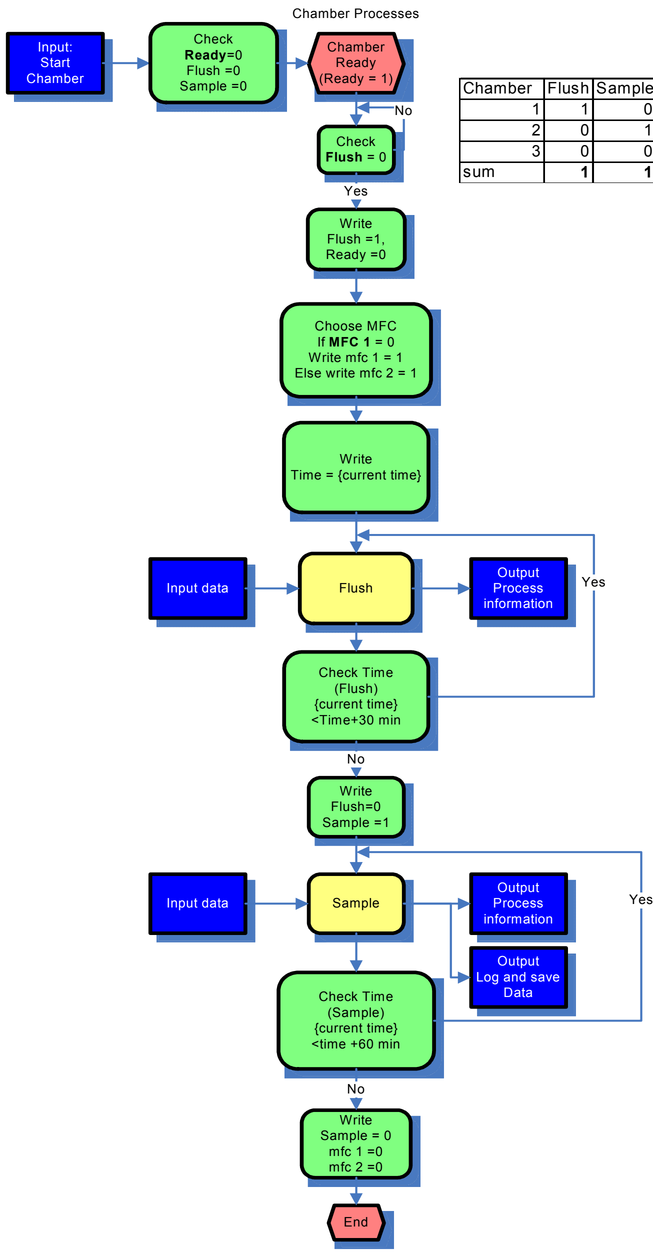


Figure 2. Multiplexer schematic.

The process structure of the multiplexer shown in figure 3 illustrates the important steps in programming the multiplexer. The data structure is presented in the top right of the flow diagram. In the data structure, a “1” indicates the component referring to the variable is active and a “0” indicates that the component is not active. The bold variables indicate the sum of the column in the data structure. To begin the process, a user presses a button that activates the chamber after it has been set. The program then checks the status of the chamber to see if it is in queue or in flushing/sampling mode. This is done by checking the variables: ready(sum), flush, and sample. If all variables are inactive, the ready variable for the individual chamber is activated. Nothing happens if any of the variables are active. The program continuously checks to see whether any chamber has changed from flush mode to sample mode. A chamber moves from flush mode to sample mode after 30 minutes. The mass flow controllers are multiplexed such that each controller is used at all times. To preserve the flow integrity, the same flow controller is used though a sample. At 60 minutes, the sampling is completed and the variables are reset for the chamber.



Chamber	Flush	Sample	Ready	mfc1	mfc2	T(chamber)
1	1	0	0	0	1	8:30
2	0	1	0	1	0	8:00
3	0	0	0	0	0	
sum	**1**	**1**	**0**	**1**	**1**	

Figure 3. Multiplexer process diagram.

Calibration

Calibration of the analyzers is performed by a dilution system. In this system calibrated gases are diluted to the required level set forth by the analyzer. A multipoint calibration system is necessary to determine the response to each level of the measured gas. The dilution system consists of two mass flow controllers. Two analyzers may be calibrated at the same time using the dilution system. One mass flow controller for the Zero air is used for the Zero air side of the dilution system as shown in figure 2. An additional Mass flow Controller (MFC3, Fig. 2) is used to meter the calibration gas. A static mixing tube is used to ensure proper mixing of the diluted gas.

Error checking

Checking for errors is an important part of any complex system. The program enables the system to check for flow rate errors and alerts the user of the error as it occurs. The error checking has several levels of errors. If an error is severe enough, the chamber is stopped and allowed to begin again. Before each sampling period, the sample lines are flushed to ensure that no condensation remains in the line from the previous sample. This is one method to reduce the chance of damaging a mass flow meter or mass flow controller.

Recording Data

Recording data is an important function of the instrumentation. Data from the analyzers is logged as well as temperatures from the chambers. Temperatures are logged using a custom built data logger with thermocouples. The temperature inside the chamber, outside the chamber, and from the source are measured and relayed back to the main computer with wireless communication where the data is processed using LabVIEW. One minute concentration averages are output from the analyzers using a serial digital interface. This allows trend analysis without a copious amount of data.

Data management

Data management plays a key role in the sampling trips. Methods by which data can be processed in the field were developed. This allows the user to gain key information once the sample is complete. The information gained includes the confidence interval for the sample, the average concentrations of ammonia and hydrogen suulfide in the sample, the average for the sampling unit (e.g. manure handling, storage and treatment, or animal confinement) and the variation within the unit. Since the number of samples to be collected is a function of the desired variation between samples and the area, onsite analysis provides a tool to make decisions about the number of samples collected from a sampling unit. To maintain data integrity, each data sheet is printed after the sample is taken. This also allows ease in identifying errors and enables correction errors before the next sample is taken.

Conclusions

The new system increases the number of samples taken, allows better retention of data and is easier to use. This allows CAAQES the use of increased productivity for the throughput of the sampling period. Although the multiplexer system was designed to operate with chambers, it may have other uses in field and laboratory sampling of air pollutants.

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